ENVIRONMENTAL GEOLOGY NOTES

DECEMBER 1972 ● NUMBER 59

NOTES ON THE EARTHQUAKE OF SEPTEMBER 15, 1972, IN NORTHERN ILLINOIS

Paul C. Heigold

ILLINOIS STATE GEOLOGICAL SURVEY

JOHN C. FRYE, Chief ● Urbana 61801

NOTES ON THE EARTHQUAKE OF SEPTEMBER 15, 1972, IN NORTHERN ILLINOIS

Paul C. Heigold

INTRODUCTION

On Friday, September 15, 1972, shortly after midnight, an earthquake shook a seven-state area of the central United States. The disturbance was centered in northern Illinois, about 7 miles south of the town of Amboy in Lee County, approximately 100 miles west of Chicago.

Seismograph stations throughout the United States recorded the shock. Preliminary analyses of the seismograms yielded the following information:

Origin time: $5^h\ 22^m\ 11^s$ Greenwich Mean Time
$12^h\ 22^m\ 11^s$ a.m. Central Daylight Time

Epicenter: Latitude 41.61°N, Longitude 88.46°W
About 7 miles south of Amboy in Lee County, Illinois

Depth of focus: Less than 15 kilometers (c. 9 mi) (probably about 6 km, or 3.6 mi)

Magnitude: 4.63 on the Richter scale (from body waves)

Maximum intensity: Barely VI on the Modified Mercalli scale

Noticeable earthquakes occur infrequently in Illinois. Therefore, whenever an earthquake of appreciable magnitude and intensity does occur, interest is naturally widespread. The Illinois State Geological Survey has prepared this Environmental Geology Note to provide information about the recent earthquake and about earthquakes in general. The earthquake that occurred in Illinois on November 9, 1968, was reported in Environmental Geology Note 24.

As was done for the 1968 earthquake, a canvass of personnel of the mineral industries, geologists, geophysicists, engineers, and members of various government agencies was made to assay the effects of the September earth-

quake. Telephone inquiries, questionnaires mailed out by the Survey, field visits by Survey personnel, and news releases afforded the information for this report.

The resulting compilation of information indicates that most observations concerned ground motion. As might be expected, the greatest shaking of structures occurred close to the epicenter, and away from the epicenter the greatest shaking was felt on the floodplains of rivers and above ancient buried valleys where unconsolidated sediments form the earth's surficial materials. Only minor damage, if any, occurred. The State Water Survey reported that no effects from the earthquake were observed in the water level records of their observation wells.

Acknowledgments

We are indebted to Dr. Otto Nuttli, Professor of Geophysics, St. Louis University, St. Louis, Missouri, and geophysicists at the National Earthquake Information Center in Boulder, Colorado, who provided information from the analyses of the seismograms of this earthquake.

MAGNITUDE, ENERGY, AND INTENSITY

Magnitude

The magnitude of an earthquake is a measure of ground movement recorded at a seismic station. It is formally defined as the logarithm (base 10) of the largest amplitude, measured in microns (0.001 mm) on the record made by a standard Wood-Anderson torsion seismometer (period = 8 sec, magnification = 2800, and damping factor = 0.8) at a distance of 100 km (62 mi) from the epicenter of the earthquake.

The term was originally defined by Richter (1935) so that the energy released in one earthquake could easily be compared with that released in other earthquakes. Richter's original work was done with data from shallow earthquakes (depth of focus less than 70 km, or 42 mi) in southern California and adjoining states.

Energy

Gutenberg (1955) and Gutenberg and Richter (1956) investigated the relation between the energy released by an earthquake and its magnitude and found that

$$\log_{10} E = 5.8 + 2.4\ M$$

where E = total energy, in ergs, released by an earthquake and M = magnitude of an earthquake determined from body waves (Richter scale).

The term "body waves" refers to waves traveling through the body of the earth. Surface waves also have been used for determining the magnitude of an earthquake.

The magnitude of the September earthquake in Illinois was 4.63 on the Richter scale (Nuttli, *personal communication*). Substitution of this value into the energy-magnitude equation yields an energy value of just under 10^{17} ergs. This is roughly only a hundredth of the energy that was released in the 1968 earthquake in southern Illinois, which had a magnitude of 5.5 on the Richter scale (Heigold, 1968).

Intensity Scales and Maps

The intensity of an earthquake is indicated by the amount of shaking, damage to property, and earth deformation felt or observed at a given place. Intensity is measured in terms of arbitrarily defined scales. Numerous intensity scales have been developed in the past, and at the present time several such scales are in widespread use. Because more than one such scale will be referred to in this paper (table 1), the evolution of the intensity scale is discussed briefly.

Intensity scales intended for general use developed gradually, as comparisons by individual investigators revealed a common pattern. DeRossi in Italy and Forel in Switzerland jointly set up the Rossi-Forel scale in 1883, and it was widely adopted in seismology and engineering. In 1902 Mercalli brought out an improved scale that had 10 grades; later the scale was revised to incorporate 12 grades. The Mercalli scale was based on a suggestion by Cancani, who attempted to express intensity grades in terms of ground acceleration. A more elaborate scale was published by Sieberg in 1923, and it was this form that was used as the basis for the Modified Mercalli scale in 1931 by H. O. Wood and Frank Neumann (Richter, 1958).

When seismological or engineering literature gives intensity numbers without a specified scale, as is often the case, it is probable that reports published prior to 1930 refer to the Rossi-Forel scale and those published thereafter refer to the Modified Mercalli scale.

An intensity map is simply one that shows how intensity, as determined from an intensity scale, is distributed throughout an area during an earthquake. If the ground were completely homogeneous and the energy were radiated uniformly in all directions from a single source (the focus), the isoseismal (equal intensity) lines would be circles. However, several factors influence the radiation of energy from the focus. First, the nature of the release of energy may be such that it is radiated more strongly in one direction than in another. Second, the source may not be a point, but may extend throughout a plane or a volume of the earth. Third, different types of earth materials transmit the vibrations with different efficiencies. Hard bedrock transmits energy better than unconsolidated sediments do. Large bodies of loose, natural or man-made fill tend to shake more severely than bedrock. Finally, certain geologic structures, such as faults, under certain circumstances bar the passage of seismic waves. Zones on the other side of such structures may receive shocks of much lower intensity than would be expected.

TABLE 1—MODIFIED MERCALLI INTENSITY SCALE OF 1931*

Scale degree	Effects on persons	Effects on structures	Other effects	Rossi-Forel equivalent	Equivalent shallow magnitude
I	Not felt except by few under favorable circumstances.			I	
II	Felt by few at rest.		Delicately suspended objects swing.	I-II	2.5
III	Felt noticeably indoors. Standing cars may rock.		Duration estimated.	III	
IV	Felt generally indoors. People awakened.		Cars rocked. Windows, etc., rattled.	IV-V	3.5
V	Felt generally.	Some plaster falls.	Dishes, windows broken. Pendulum clocks stop.	V-VI	
VI	Felt by all. Many frightened.	Chimneys, plaster damaged.	Furniture moved. Objects upset.	VI-VII	
VII	Everyone runs outdoors. Felt in moving cars.	Moderate damage.		VIII	5.5
VIII	General alarm.	Very destructive and general damage to weak structures. Little damage to well built structures.	Monuments, walls down. Furniture overturned. Sand and mud ejected. Changes in well-water levels.	VIII-IX	6
IX	Panic.	Total destruction of weak structures. Considerable damage to well built structures.	Foundations damaged. Underground pipes broken. Ground fissured and cracked.	IX	
X	Panic.	Masonry and frame structures commonly destroyed. Only best buildings survive. Foundations ruined.	Ground badly cracked. Rails bent. Water slopped over banks.	X	
XI	Panic.	Few buildings survive.	Broad fissures. Fault scarps. Underground pipes out of service.	X	8.0
XII	Panic.	Total destruction.	Acceleration exceeds gravity. Waves seen in ground. Lines of sight and level distorted. Objects thrown in air.	X	8.5

*After Wood and Neumann, 1931; Richter, 1958.

The shaking of the ground or a building during an earthquake depends not only on the nature of the earthquake waves being received, but also on the nature of the receiver. Wave motion of any kind can be transmitted in any system in three ways—by reflection, by perfect transmission, and by absorption. Absorption is of particular importance in a structure, either natural or man-made, that is shaken by an earthquake. If energy is transmitted more slowly than it is supplied, it will accumulate in the structure, with a gradual increase in amplitude of vibration. The shaking then may become violent enough to do heavy damage. This is common on certain types of ground, especially filled land, whether it be man-made fill or the loose sediments of rivers or lake beds. In such places the ground commonly vibrates much more than adjoining sections of more solid rock. Buildings have certain natural frequencies of vibration. If they are shaken at these frequencies, the amplitude may build up until it is much greater than that in the underlying ground.

A preliminary intensity map for the September earthquake appears in figure 1. Field visits by Survey personnel to over 100 towns in Illinois and conversations with their inhabitants shortly after the earthquake provided the bulk of the information used in preparing the map. The conversations and observations were geared to elicit information similar to that outlined in the questionnaire cards circulated by the U. S. Coast and Geodetic Survey to determine intensities.

At any particular location, the information gathered from individuals on the intensity of the quake varies greatly. The men making the canvass assigned intensity values on the basis of their conversations with individuals. In each locality an intensity value was assigned to each individual account. The statistical mode of these accounts was then calculated and assigned as the intensity value for that locale.

The maximum intensity value associated with the September earthquake was barely over VI on the Modified Mercalli scale, well below the value of VIII generally regarded as the lower limit of serious damage to man-made structures. The mesoseismal area (the area enclosed by the maximum intensity isoseismal) includes the epicenter (the point on land surface above the focus of the quake). This is not always the case, for it depends on how the energy was radiated from the focus. The two greatest isoseismals are elongated in the north-south and northwest-southeast directions (fig. 1). Elongations of this sort often are aligned with known major structural trends and possibly with the orientation of faulting at depth.

Significantly, areas of high intensity occurred along the Mississippi, Illinois, Fox, and Rock Rivers and the ancient buried Princeton bedrock valley. Towns in these areas experienced greater shaking than neighboring towns. A more detailed intensity survey would undoubtedly show increased shaking wherever loose, unconsolidated sediments are present.

CAUSES OF EARTHQUAKES

The ultimate cause of most earthquakes is the build-up of great stresses in the earth. It is generally believed that these stresses produce faulting

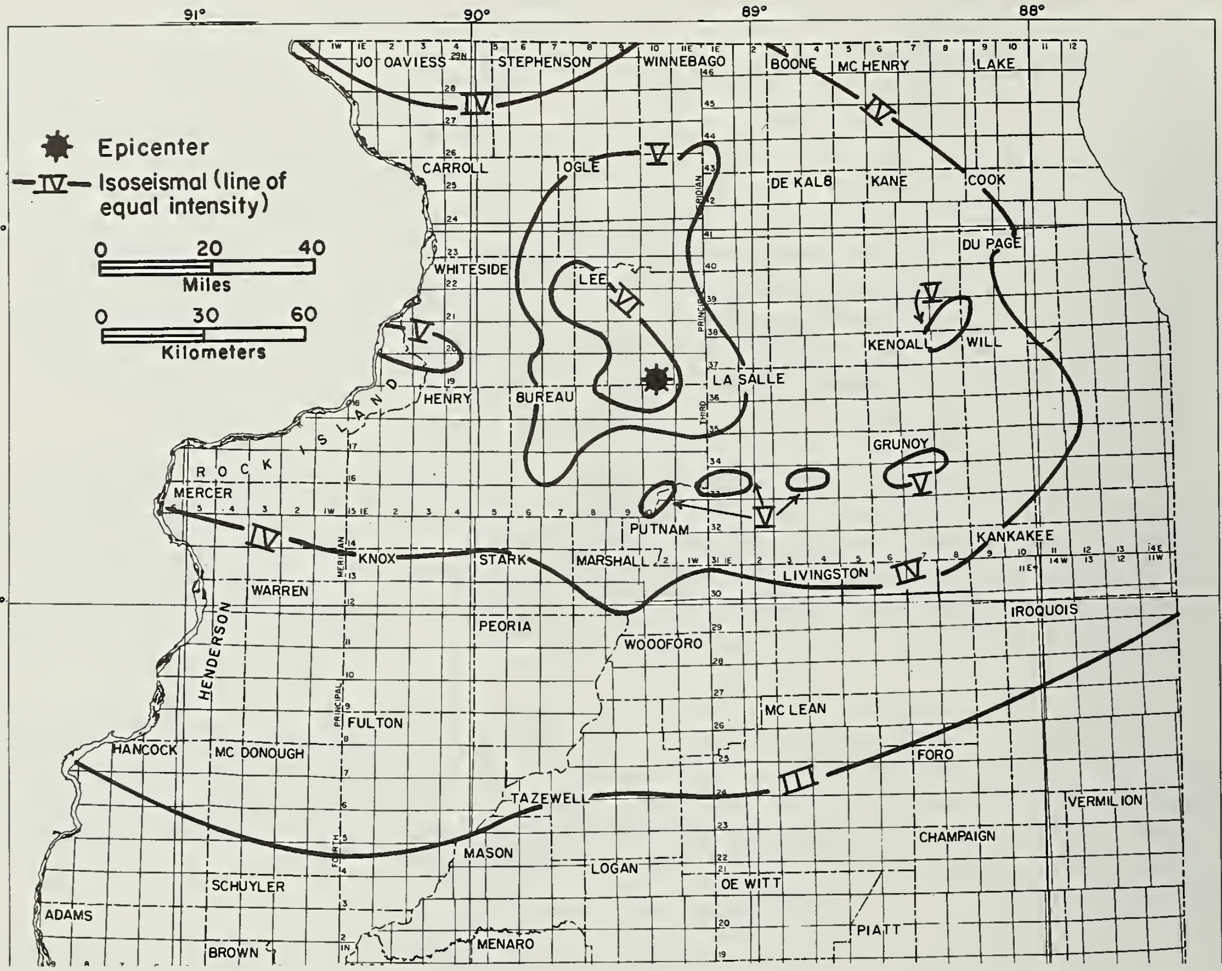


Fig. 1 - Intensity map of the northern Illinois earthquake of September 15, 1972. Intensities refer to the 1931 Modified Mercalli scale.

(relative movement of blocks of rock along a fracture), which is considered to be the immediate cause of most earthquakes. The reasons for this belief are: (a) many earthquakes have been accompanied by movement of blocks of earth along faults visible at land surface; and (b) even where no signs of surface dislocation are apparent along known faults during earthquakes, epicenters and regions of maximum intensity of earthquakes commonly lie along faults or other geologically recognized zones of weakness. In the latter case it is assumed that the faults have occurred at depth, but the dislocation has not extended to the surface.

In Illinois, the faults recognized at land surface have shown no signs of dislocation during historically observed earthquakes or even during post-Cretaceous time. According to Byerly (1942) "...when considering the great number of earthquakes on record, the number accompanied by marked surface rupture is seen to be pitifully few."

Repeated earthquakes commonly occur along the same structural trends in earthquake-prone areas, probably because accumulated stress overcomes the static friction on an old fault surface instead of breaking fresh rocks. On the other hand, it is not known how much a fault break may "heal." Near the surface a fault zone may be much fractured and appear to be a zone of obvious weakness, but at greater depths such zones may not persist or may be quite firmly cemented.

Earthquake epicenters do not invariably line up along known faults or zones of weakness that are apparent at land surface. Presumably those that do not are related to faults at depth that are not recognizable at the surface.

Most earthquakes are of the shallow focus variety (focal depth less than 70 km, or c. 42 mi). In general, both the number of earthquakes and the energy associated with earthquakes decrease with depth of focus. This seems to indicate that the rocks in the earth's crust (above a depth of 70 km) can accumulate greater amounts of stress before breaking than the rocks of the underlying mantle. The deeper rocks yield plastically to stress.

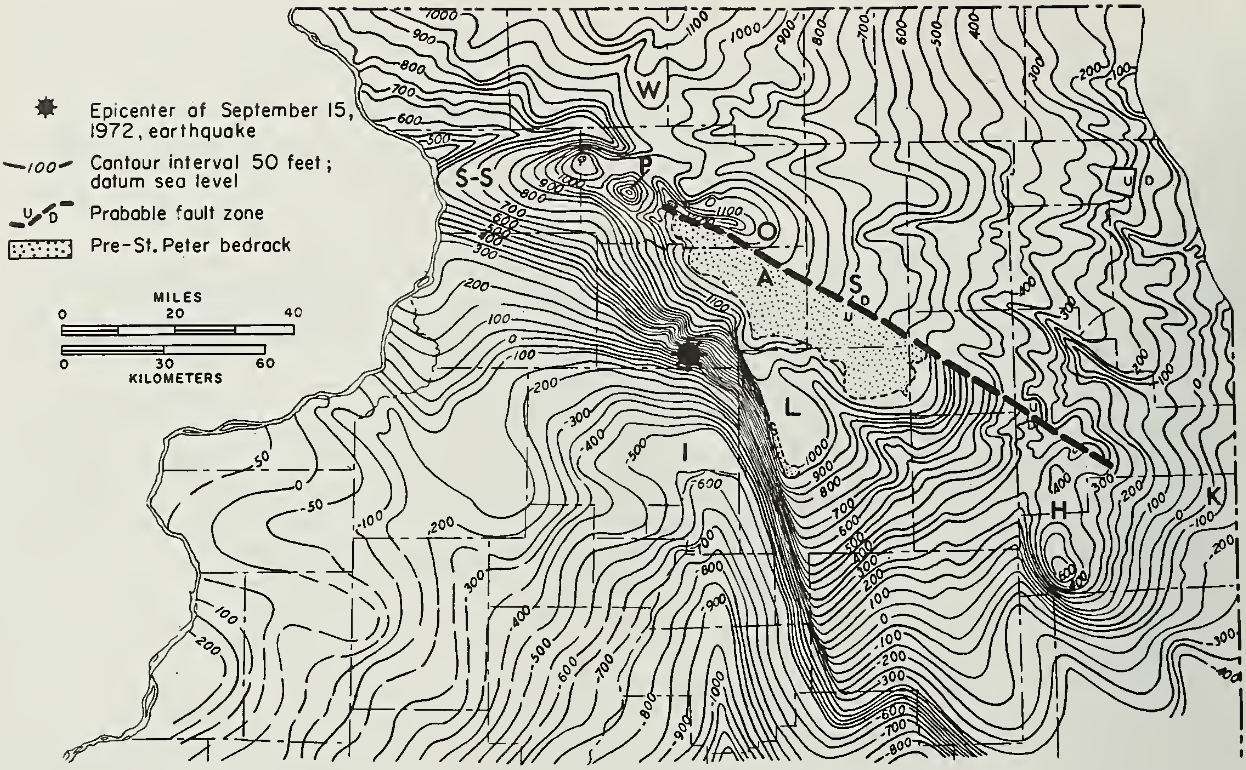
GEOLOGIC SETTING OF SEPTEMBER 15 EARTHQUAKE

The September 15, 1972, earthquake had a focal depth of less than 15 km (c. 9 mi). This places the focus within the earth's crust, which is about 35 km (c. 21 mi) thick for that area of northern Illinois (Heigold, 1960). The continental crust consists of sedimentary rocks overlying denser, crystalline, granitic, and basic igneous rocks, which are called "basement" rocks.

The epicenter of the September earthquake was at the northern end of the Illinois Basin (fig. 2). Just a few miles north of the epicenter are two deep wells that penetrate basement rock (Bradbury and Atherton, 1965). One well encountered red granite at a depth of 3760 feet and the other hit red granite and felsite at a depth of 3465 feet. The uppermost bedrock at the epicenter is Silurian dolomite, which is overlain by approximately 400 feet of glacial drift (Piskin and Bergstrom, 1967).

The rocks are flexured and broken at several places in northern Illinois, as is evidenced from the structural contours of the top of the Champlainian (middle Ordovician) Galena Dolomite Group (fig. 2). The area is underlain by a complex of arches, anticlines, synclines, fault zones, and domes.

The Ashton Arch, a major anticline, trends N60°W across northern Illinois from Will County to central Ogle County and is bounded on the north throughout most of its length by the Sandwich Fault Zone, a high-angle fault with displacement of as much as 1000 feet in places (McGinnis, 1966). A graben (downfaulted block) and a syncline (down fold) separate the western part of the arch from the smaller, parallel Oregon Anticline on the north. A syncline also separates the eastern part of the arch from the La Salle Anticlinal Belt, which merges into the arch along the La Salle and Lee Counties line. A southward prong of the arch extends northwestward from Dixon to the Savanna-Sabula Anticline. The southwestward flank on the Ashton Arch dips steeply into the Illinois Basin. The western end plunges into the small but deep Polo Basin. The Kankakee Arch



W - Wisconsin Arch
SS - Savannah-Sabula Anticline
P - Polo Basin
A - Ashton Arch
L - La Salle Anticlinal Belt
S - Sandwich Fault Zone
H - Herscher Anticline
K - Kankakee Arch
O - Oregon Dome
I - Illinois Basin

Fig. 2 - Structure contours on the Galena Dolomite in northern Illinois. (After Willman and Templeton, 1951.)

is a broad uplift that connects the Wisconsin Arch with the Cincinnati Arch and separates the Illinois and Michigan Basins.

The location of the epicenter of the September 15 earthquake, along with the location and shape of the maximum intensity isoseismals, suggest that faulting within the crust is related to a zone of weakness near the region where the La Salle Anticline merges with the Ashton Arch.

To bear out the previous statement that surficial faults in Illinois have shown no displacements during historically observed earthquakes, no displacements were observed in the surficial rocks during or after the September 15 earthquake, and the energy released was not sufficient to allow enough recording stations to record first motions accurately, the data needed for a focal mechanism study. Therefore, determination of the orientation of the fault plane, the direction of relative movement along the fault plane, and the direction in which regional stresses were applied to the focal region must be based on earthquake intensity, structural geology, and other geophysical data.

The gravity field of northern Illinois provides further information concerning zones of weakness. The Bouguer gravity anomaly surface (McGinnis,

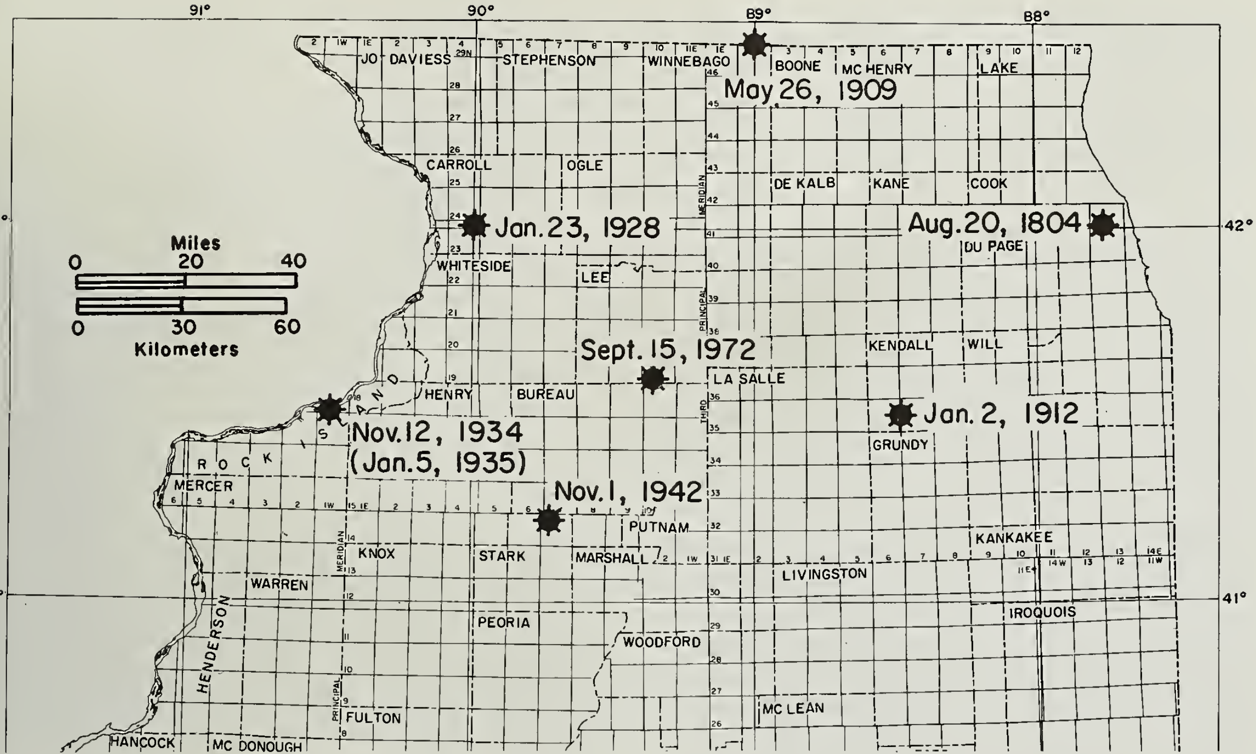


Fig. 3 - Epicenters of northern Illinois earthquakes.

1966) shows a rather large negative anomaly between the La Salle Anticlinal Belt on the west and the Sandwich Fault Zone on the north. The cause of this anomaly is undoubtedly related to a lack of isostatic compensation, which produces lateral density contrasts at depth. Until complete isostatic adjustment takes place, it must be assumed that the above-mentioned structures will be zones of weakness where future movement might occur.

EARTHQUAKE HISTORY OF NORTHERN ILLINOIS

Earthquakes centered in northern Illinois have been infrequent and nondestructive. Records dating back to 1804 indicate that no earthquakes with intensities greater than VIII on the Modified Mercalli scale have occurred in the region. Figure 3 shows the locations of some of the earthquakes for which intensities have been determined.

The earliest recorded earthquake in northern Illinois occurred on August 20, 1804, at Fort Dearborn, which is now Chicago (Eppley, 1958). The epicentral coordinates of this quake were approximately 42.0°N and 87.8°W. As nearly as can be determined, the maximum intensity of this disturbance was about VI on the Rossi-Forel scale. The area throughout which the tremor was "felt" is approximately 30,000 square miles. The "felt" area is generally

regarded as that area enclosed by the intensity III isoseismal on the Modified Mercalli Scale. People at Fort Wayne, Indiana, 200 miles from the epicenter, are recorded as feeling the quake.

On May 26, 1909, another earthquake occurred in northern Illinois. This time the area where tremors were felt extended from Missouri to Michigan and from Minnesota to Indiana, an area approximately 800 miles in diameter. The maximum intensity isoseismal of VII on the Rossi-Forel scale associated with this quake encloses a T-shaped area extending from Platteville, Wisconsin, to Waukegan, Illinois, on the north and to Bloomington, Illinois, on the south. The United States Coast and Geodetic Survey assigned epicentral coordinates of 42.5°N and 89.0°W (near the Illinois-Wisconsin border) to this quake. J. A. Udden (1910), after gathering items from newspapers published in the disturbed area and making observations in more than 100 different localities, constructed an intensity map of the disturbed area (fig. 4).

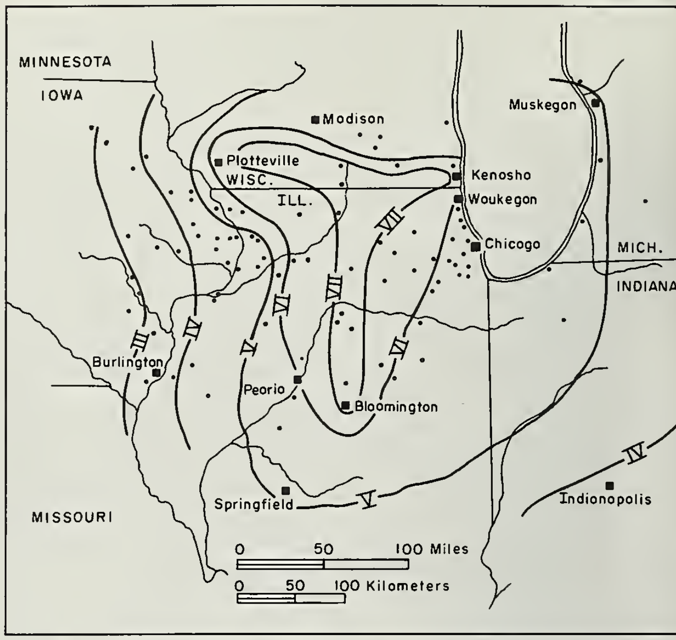


Fig. 4 - Intensity map of the Upper Mississippi Valley earthquake of May 26, 1909. Intensities refer to the Rossi-Forel scale. (After J. A. Udden, 1912.)

On January 2, 1912, another earthquake struck northern Illinois. This time the epicenter (41.5°N and 88.5°W) was located near the city of Aurora, in Kendall County. The maximum intensity was VI on the Rossi-Forel scale, and the affected area was approximately 40,000 square miles. A. D. Udden (1912) collected information concerning the effects of this earthquake and constructed an intensity map (fig. 5). Of interest on this map is the intensity V isoseismal that includes the area around Dixon. Udden apparently had misgivings about putting an isolated closure around Dixon and as an alternative extended the closure around Aurora to include Dixon. Aurora and Morris, the largest communities enclosed by the maximum intensity isoseismal, are both located along rivers—the Fox and Illinois, respectively—and Dixon is situated on the Rock River. Presumably the more severe ground shaking observed at Aurora, Morris, and Dixon was related to the presence of unconsolidated river sediments under parts of the towns.

On January 23, 1928, a small shock with a maximum intensity of less than V on the Rossi-Forel scale was epicentrically located at 42.0°N and 90.0°W, near Mt. Carroll. The area affected was very small, only 400 square miles.

On November 12, 1934, an earthquake of maximum intensity VI on the Rossi-Forel scale shook northwestern Illinois and adjacent parts of Iowa. This quake was centered near the Quad Cities of Rock Island, Moline, and East Moline, Illinois, and Davenport, Iowa. Epicentral coordinates were determined as 41.5°N and 90.5°W. Seismographs at St. Louis University, 197 miles from the epicenter,

recorded this quake. F. M. Fryxell (1940) gathered information concerning the effects of this disturbance and constructed a simple intensity map that consisted of concentric elliptical isoseismals with the major axes aligned slightly east of north (fig. 6). Such an intensity map should be viewed as schematic. Any intensity map taking into account local variations in intensity due to local conditions, such as the types of building construction and the nature of the surficial materials, would certainly be more complex.

Seven weeks later, on January 5, 1935, earth tremors were again felt in the Quad Cities area. This quake had the same epicenter as the November 12, 1934, quake. The maximum intensity of the second quake was IV on the Rossi-Forel scale and was not felt beyond the Quad Cities and the fringe of border towns. As far as is known there are no seismograph records of this earthquake. Logically, this earthquake should be considered an aftershock of the 1934 quake, and the total energy release from both quakes should be considered the result of one diastrophic event spanning a seven-week period.

Finally, the last noteworthy earthquake in northern Illinois prior to the one that is discussed in this paper occurred on March 1, 1942. This quake was about 9 miles east of Kewanee in Henry County (41°14'N and 89°44'W). It was felt in Rock Island, Henry, Bureau, Mercer, Knox, Stark, and Peoria Counties. Its maximum intensity was about V on the Modified Mercalli scale. Perhaps its most interesting aspect is the proximity of its epicentral coordinates to those of the September 1972 earthquake.

This history of northern Illinois earthquakes is by no means complete. Although all known quakes in the area have been of relatively low intensity, only the more intense, recorded earthquakes have been mentioned here. Exact seismological information has been available for only the last 60 years. Prior to that, earthquake information came from personal observations, so the record is spotty. Undoubtedly many other earthquakes have occurred in this region in the last two centuries that were too feeble to be reported.

Fig. 5 - Intensity map of the Upper Mississippi Valley earthquake of January 2, 1912. Intensities refer to the Rossi-Forel scale. (After A. D. Udden, 1912.)

NORTHERN ILLINOIS EARTHQUAKE HAZARDS

The exact manner in which earthquake-causing stresses accumulate and are relieved in northern Illinois is not known. Therefore, in order to gain insight into the earthquake hazards of this region we can only use data from past earthquakes that have affected the region, in conjunction with our present knowledge of the structural and surficial geology of the region. Admittedly, this approach has its shortcomings because the earth is dynamic and the application of stresses may be different in the

future. The frequency and magnitudes of past earthquakes affecting a region give some idea of the stress build-up and energy release as a function of time. Epicentral coordinates of past earthquakes considered with the structural geology of a region indicate which zones of weakness in the earth have been and/or are seismically active.

The magnitude and intensity distributions of past earthquakes, the relation between which seems to remain generally the same for a given region, provide information concerning the ground-motion parameters—particle amplitude, velocity, and acceleration. In engineering and construction work, values are usually assigned to one or more of these parameters to designate the amount of shaking a structure can withstand before failure occurs. As noted previously, ground motion is greatly influenced by surficial materials. Therefore, maps showing the nature and thickness of the unconsolidated material of a region can explain anomalously high intensity values during past earthquakes as well as pinpointing those places where ground motion may be severe during future quakes.

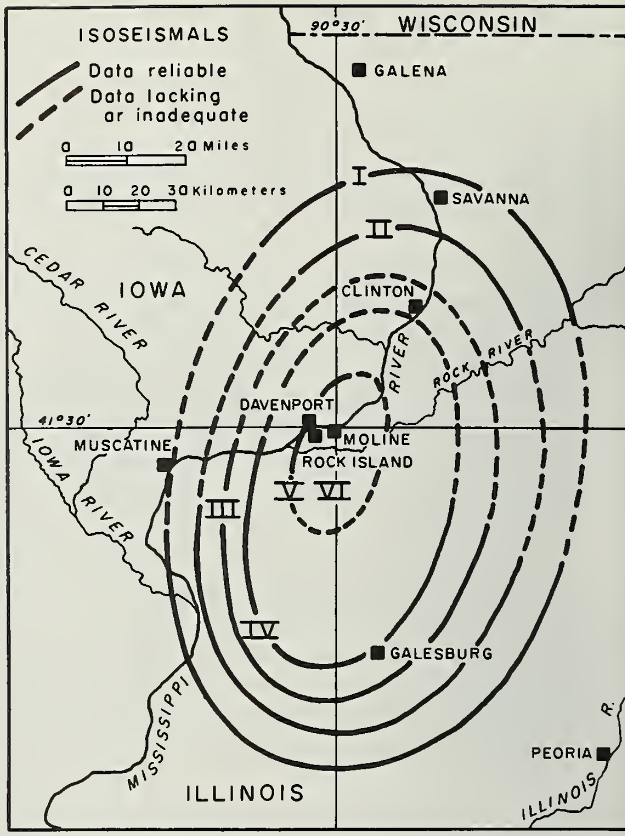


Fig. 6 - Intensity map of November 12, 1934, earthquake in northwestern Illinois and adjacent parts of Iowa. Intensities refer to the Rossi-Forel scale. (After Fryxell, 1940.)

Earthquakes having epicenters in northern Illinois, such as those discussed earlier in this paper, have been neither frequent nor severe. Their maximum intensity values have been less than VIII on the Modified Mercalli scale, and they have caused no serious damage.

This region has also been affected by earthquakes with epicenters in more seismically active areas, such as the New Madrid seismic zone that includes a portion of southern Illinois. The three principal shocks of the great 1811-1812 earthquakes that had epicenters near New Madrid, Missouri, had estimated body-wave magnitudes of 7.2, 7.1, and 7.4 (Nuttli, 1972). Nuttli constructed an intensity map for the 7.2 magnitude shock of December 16, 1811 (fig. 7), that shows maximum intensity values near the epicenter were greater than X on the Modified Mercalli scale and intensity values in northern Illinois were between V and VII. Although the New Madrid seismic zone has been active since the great 1811-1812 earthquakes, no earthquakes of large magnitude have occurred subsequently. Stauder and Nuttli (1970), on the basis of a focal mechanism study, associated the November 9, 1968, earthquake with movement along the Wabash Valley Fault System, which intersects the land surface 12 miles east of its epicenter. This earthquake had a magnitude of 5.5, and it was the largest earthquake in this region since St. Louis University's seismograph station began operations in 1909.

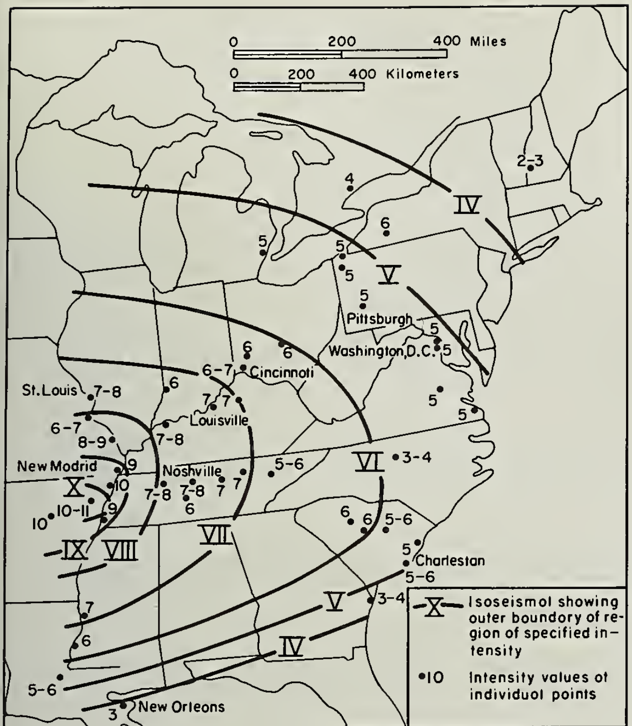


Fig. 7 - Generalized intensity map of the Mississippi Valley earthquake of December 16, 1811. Intensities refer to the 1931 Modified Mercalli scale. (After Nuttli, 1972.)

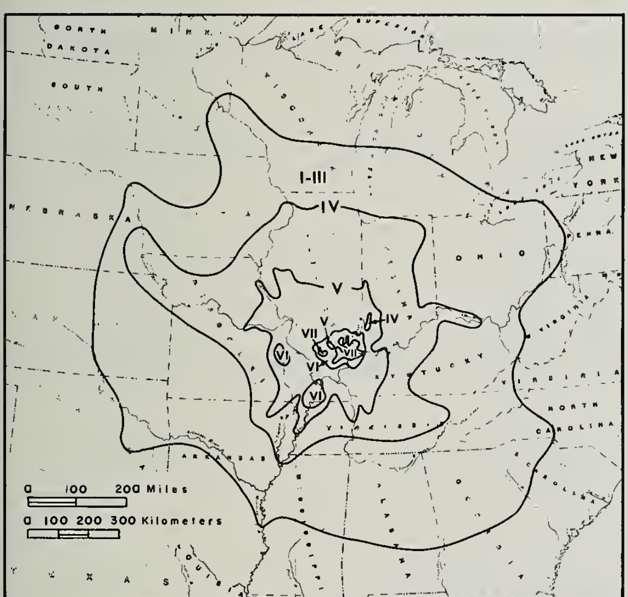


Fig. 8 - Intensity map of the southern Illinois earthquake of November 9, 1968. Intensities refer to the 1931 Modified Mercalli scale. (After Gordon et al., 1970.)

Maximum intensity values for the 1968 earthquake were about VII near the epicenter and between IV and V in northern Illinois (fig. 8). Other noteworthy earthquakes with epicenters in and around Illinois have occurred besides those associated with the New Madrid seismic zone and those in northern Illinois already mentioned. These earthquakes, which originated in zones of weakness outside of northern Illinois, have been similar in magnitude and frequency to those of northern Illinois.

Assuming that future earthquakes affecting northern Illinois will be much like those experienced in the past, it can be predicted that their maximum intensity values will, in general, approach but be less than the intensity value associated with serious damage to man-made structures. In areas where surficial materials, such as those under portions of floodplains, tend to enhance ground motion, the maximum expected intensity values may be increased as much as one unit on the Modified Mercalli scale and thereby increase the possibility of damage. Judging from the seismic history of the area, an earthquake centered in northern Illinois will be less hazardous than an earthquake centered in the New Madrid seismic zone.

REFERENCES

Bradbury, J. C., and Elwood Atherton, 1965, The Precambrian basement of Illinois: Illinois Geol. Survey Circ. 382, 13 p.

Byerly, Perry, 1942, Seismology: Prentice-Hall, Inc., New York, 256 p.

Eppley, R. A., 1958, Earthquake history of the United States, Part 1—Continental United States and Alaska (exclusive of California and western Nevada): Revised ed. (through 1956), no. 41-1, U. S. Coast and Geodetic Survey, Washington, D.C., 80 p.

Fryxell, F. M., 1940, The earthquakes of 1934 and 1935 in northwestern Illinois and adjacent parts of Iowa: Seis. Soc. America Bull., v. 30, no. 3, p. 213-218.

Gordon, D. W., T. J. Bennett, R. B. Herrmann, and A. M. Rogers, 1970, The south-central Illinois earthquake of November 9, 1968: Macroseismic studies: Seis. Soc. America Bull., v. 60, no. 3, p. 953-971.

Gutenberg, Beno, 1955, Wave velocities in the earth's crust: Geol. Soc. America Spec. Paper 62, p. 19-34.

Gutenberg, Beno, and C. F. Richter, 1956, The energy of earthquakes: Geol. Soc. London Quart. Jour. 112, p. 1-14.

Heigold, P. C., 1960, Crustal thickness of the St. Louis area determined by the phase velocity of Rayleigh waves: St. Louis Univ. M.S. thesis, St. Louis, Mo.

Heigold, P. C., 1968, Notes on the earthquake of November 9, 1968, in southern Illinois: Illinois Geol. Survey Environmental Geology Note 24, 16 p.

McGinnis, L. D., 1966, Crustal tectonics and Precambrian basement in northern Illinois: Illinois Geol. Survey Rept. Inv. 219, 29 p.

Nuttli, O. W., 1972, The Mississippi Valley earthquakes of 1811 and 1812: Intensities, ground motion and magnitudes: Study supported by Grant GA-20115 of the Natl. Sci. Found., Earth Sciences Sec., 32 p.

Piskin, Kemal, and R. E. Bergstrom, 1967, Glacial drift in Illinois: Thickness and character: Illinois Geol. Survey Circ. 416, 33 p.

Richter, C. F., 1935, An instrumental earthquake magnitude scale: Seis. Soc. America Bull., v. 25, p. 1-32.

Richter, C. F., 1958, Elementary seismology: W. H. Freeman and Company, San Francisco, 768 p.

Sieberg, A., 1923, Erdbebenkunde: Fischer, Jena, p. 102-104.

Stauder, W., and O. W. Nuttli, 1970, Seismic studies: South-central Illinois earthquake of November 9, 1968: Seis. Soc. America Bull., v. 60, no. 3, p. 973-981.

Udden, J. A., 1910, Observations on the earthquake in the Upper Mississippi Valley, May 26, 1909: Illinois Acad. Sci. Trans., v. 3, p. 132.

Udden, A. D., 1912, On the earthquake of January 2, 1912, in the Upper Mississippi Valley: Illinois Acad. Sci. Trans., v. 5, p. 111.

Willman, H. B., and J. S. Templeton, 1951, Cambrian and lower Ordovician exposures in northern Illinois: Illinois Acad. Sci. Trans., v. 44, p. 109-125.

Wood, H. O., and Frank Neumann, 1931, Modified Mercalli Intensity Scale of 1931: Seis. Soc. America Bull., v. 21, p. 278-283.

ENVIRONMENTAL GEOLOGY NOTES SERIES

(Exclusive of Lake Michigan Bottom Studies)

* Out of print.